RESEARCH ARTICLE

Habitat preference and potential distribution of *Magnolia officinalis* subsp. *officinalis* and *M. o.* subsp. *biloba* in China

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Abstract

Magnolia officinalis subsp. *officinalis* and *M. officinalis* subsp. *biloba* are important medicinal plants in China. The bark of these two subspecies is commonly used in the production of a widely-used Chinese traditional medicine named 'Houpu'. In recent years, *M. o.* subsp. *officinalis* and *M. o.* subsp. *biloba* have become increasingly threatened owing to the over-harvesting of their bark and the fragmentation of their habitats. In this study, we aimed to support the conservation and cultivation of these two subspecies in China by: (1) assessing the relationship between numerous environmental variables and the geographical distributions of the subspecies; (2) analysing the environmental characteristics of suitable habitats for both subspecies and predicting the spatial distribution of these habitats in China; and (3) identifying conservation areas of both subspecies in China via overlay analysis. We also assessed the degree of human disturbance within suitable habitats. We found that temperature was a major determinant for the distribution of *M. o.* subsp. *officinalis*. Conversely, the distribution of *M. o.* subsp. *biloba* was primarily dependent on precipitation rather than temperature. Distinct habitat preferences were observed between *M. o.* subsp. *officinalis* and *M. o.* subsp. *biloba*. Suitable habitats of *M. o.* subsp. *officinalis* were primarily distributed in the northern subtropical areas of China, with greater fluctuations in ambient temperature, lower extreme temperatures, less precipitation and greater fluctuations in precipitation. Habitats suitable for *M. o.* subsp. *biloba* were highly fragmented and were distributed in the central subtropical areas of China. We found that a large proportion of suitable habitats were not in the protected areas and that they were significantly disturbed by human activity. This analysis could provide useful information for the conservation of both *M. o.* subsp. *officinalis* and *M. o.* subsp. *biloba* and could aid in the selection of cultivation sites.

Introduction

Magnolia officinalis subsp. *officinalis* and *M. officinalis* subsp. *biloba* are two important medicinal plants in the Magnoliaceae. The bark of these subspecies is used to make a famous traditional Chinese medicine named 'Houpu'. Houpu has been widely used in traditional Chinese medicinal practices for around 2000 years. Houpu has traditionally been thought to promote the flow of "qi" and blood and to reduce negative energy (Chinese Pharmacopoeia Commission 2015). The active ingredients of Houpu are magnolol and honokiol, both of which are known to possess broad pharmacological qualities, including anti-microbial, anti-inflammatory, anti-tumour and anti-aging effects and are also thought to aid muscle relaxation and cholesterol removal (Wang et al. 2005).

The demand for Houpu has increased dramatically over the last few decades. However, *M. o.* subsp. *officinalis* and *M. o.* subsp. *biloba* grow at a relatively slow rate and bark can only be harvested from trees that are more than 15 years old. This has led to the over-harvesting of *M. o.* subsp. *officinalis* and *M. o.* subsp. *biloba* bark. In addition, the two subspecies have poor natural reproductive capacities (Liu et al. 1997) and their habitats have been greatly disturbed by human activity. As a result, wild *M. o.* subsp. *officinalis* and *M. o.* subsp. *biloba* populations are greatly threatened and are at risk of extinction (Xiong et al. 2009). *Magnolia o.* subsp. *officinalis* and *M. o.* subsp. *biloba* are ranked as category II protected plant species (http://www.gov.cn/gongbao/content/2000/content_60072.htm) and have been identified as national key protected wild medicinal materials (http://www.forestry.gov.cn/portal/ynb/s/4769/content-802380.html). More recently, significant efforts have been made to conserve wild *M. o.* subsp. *officinalis* and *M. o.* subsp. *biloba* populations. However, these wild populations are still at risk in China. Therefore, further efforts are required to conserve wild *M. officinalis* subsp. *officinalis* and *M. o.* subsp. *biloba* populations.

Habitat conservation is an efficient way to protect threatened species (Maxted et al. 2008). To improve the practicality and effectiveness of habitat conservation, it is essential to first understand the habitat preferences and distributions of at-risk species. This is imperative for the conservation of *M. o.* subsp. *officinalis* and *M. o.* subsp. *biloba* populations. Although *M. o.* subsp. *officinalis* and *M. o.* subsp. *biloba* have a close phylogenetic relationship, they have different geographical distribution areas (Liu 1996). However, few studies have quantitatively assessed their habitat characteristics and evaluated habitat suitability for these two subspecies. Recently in China, during the conversion of farmland to forest, local governments have made significant efforts to promote the cultivation of *M. o.* subsp. *officinalis* and *M. o.* subsp. *biloba*. The medicinal efficacy of Houpu is closely related to the environmental conditions of the plants' habitat (Zhang et al. 2017). Inappropriate selection of cultivation sites not only results in the wasting of land and economic losses on the part of the farmers,

but also reduced the medicinal quality of the Houpu. Therefore, proper evaluation of habitat suitability is essential for the cultivation and conservation of *M. o.* subsp. *officinalis* and *M. o.* subsp. *biloba*.

Thus, the objectives of this study were to: (1) analyse the relationship between environmental conditions and the distribution of *M. o.* subsp. *officinalis* and *M. officinalis* subsp. *biloba* and to improve our understanding of their habitat preferences; (2) estimate the spatial distribution of suitable habitats in China; and (3) identify the conservation areas and the extent of human disturbance in the suitable habitats. We hope this research will provide technical support for the conservation and cultivation of *M. o.* subsp. *officinalis* and *M. o.* subsp. *biloba* in China.

Methods

Spatial distribution of *M. o.* subsp. *officinalis* and *M. o.* subsp. *biloba*

According to the Flora of China (Volume 30(1)) (Liu 1996), *M. officinalis* subsp. *officinalis* is mainly distributed in the northern and central subtropical regions, which includes the southern area of Shaanxi province, the south-eastern areas of Gansu province and Henan province, the western area of Hubei province, the south-western area of Hunan province, the central and eastern areas of Sichuan province and the north-eastern area of Guizhou province (Fig. 1). *Magnolia o.* subsp. *biloba* is mainly distributed in the central subtropical regions, which includes the western areas of Anhui province and Zhejiang province, the southern areas of Jiangxi province, Fujian province and Hunan province, the northern area of Guangdong province and the northern and north-eastern areas of Guangxi province (Fig. 1).

A total of 241 specimens were reviewed from the Chinese Herbarium (http://www. cvh.ac.cn/) to retrieve the distribution information of *M. o.* subsp. *officinalis* and *M. o.* subsp. *biloba*. As most specimens were identified as *M. o.* in the original background information of these specimens, we invited plant taxonomists to re-identify these specimens to the level of subspecies.

We also collected geographical distribution information for both subspecies from the published literature (Zhang et al. 2009; Yu et al. 2010; Wang et al. 2016; Yan et al. 2016). Specifically, specimen records of cultivated trees were excluded from the dataset. Finally, 163 records of *M. o.* subsp. *officinalis* and 106 records of *M. o.* subsp. *biloba* were used to estimate the habitat suitability, respectively (Fig. 1).

Environmental variables

Information on nineteen bioclimatic variables was retrieved from WorldClim (http://www.worldclim.org/) (Table 2). We used the averages for each of the years from 1970 to 2000 and were of spatial resolution 2.5' (Hijmans et al. 2005).
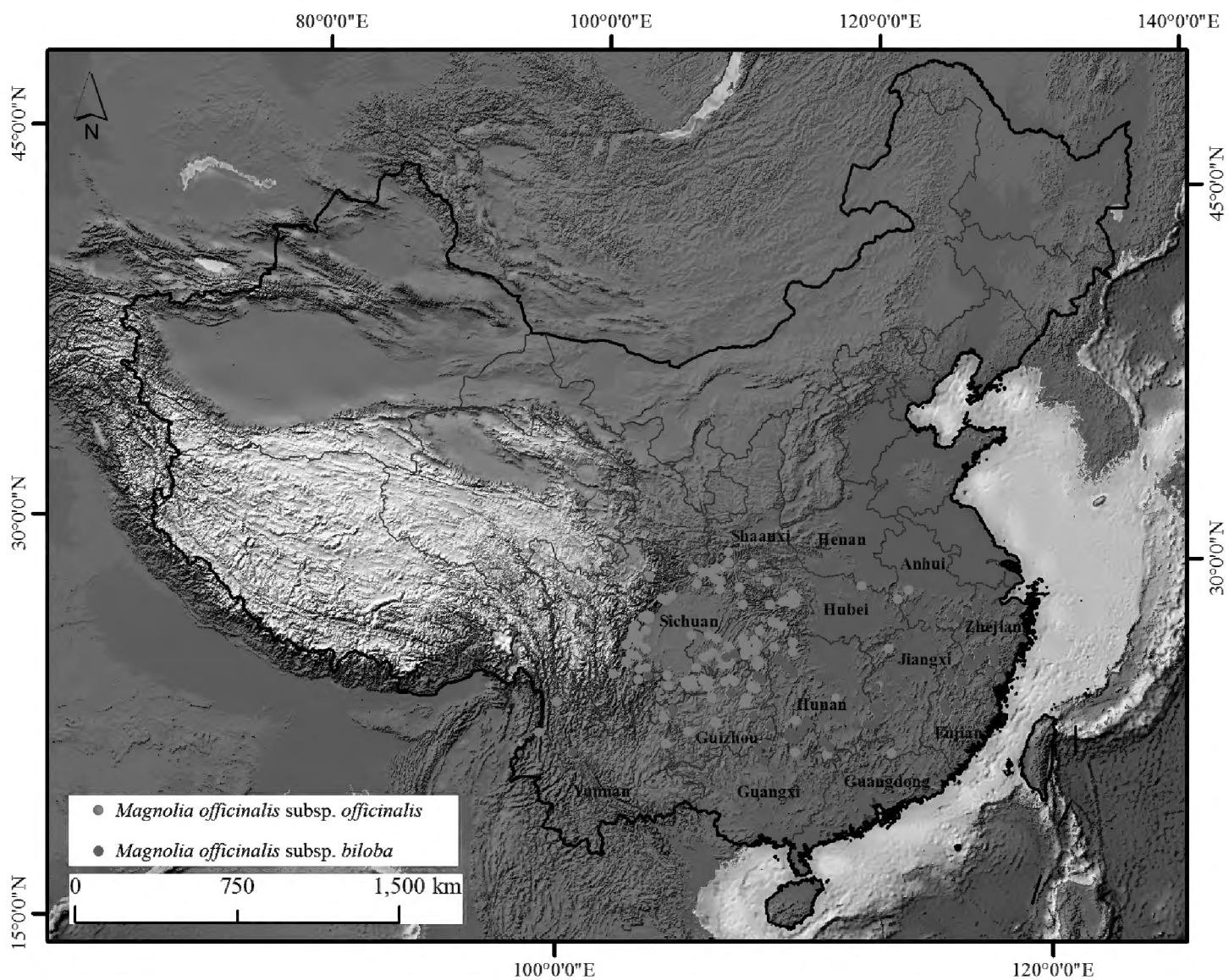
Figure 1. The distributions of *Magnolia officinalis* subsp. *officinalis* and *M. officinalis* subsp. *biloba* in China.

Table 1. Permutation importance of each environmental variable in determining *Magnolia officinalis* subsp. *officinalis* and *M. officinalis* subsp. *biloba* distributions

Variable	*M. o.* subsp. *officinalis*	*M. o.* subsp. *biloba*
altitude [m]	8.8	0.3
aspect [°]	0.1	0.1
slope [°]	0	0.1
temperature seasonality	11.1	18.5
min. temperature of coldest month [°C]	74.4	1.5
mean temperature of wettest quarter [°C]	0	1.4
mean diurnal range [°C]	1.5	4.2
annual precipitation [mm]	2.3	72.4
precipitation of warmest quarter [mm]	0.7	0.5
precipitation of driest month [mm]	1.1	1

The Advanced Spaceborne Thermal Emission and Reflection Radiometer Global Digital Elevation Model (ASTER GDEM) was used to derive topographic variables in this research. The vertical accuracy of the ASTER GDEM is 20 m and its horizontal accuracy is 30 m with 95% confidence (ASTER GDEM Validation Team 2011). We

Table 2. Approximate ranges of environmental variables suitable for each subspecies based on response curves

	Environmental variable	Environmental ranges for *M. o.* subsp. *officinalis*	Environmental ranges for *M. o.* subsp. *biloba*
Topography	altitude [m]	845–1750	156–594
	aspect[°]	87–151	68–140
Temperature	annual mean temperature [°C]	11–15	16–19.5
	mean diurnal range [°C]	6.7–9.2	6.4–7.8
	isothermality	26–30	25–28.5
	temperature seasonality	663–775	687.5–787.5
	max. temperature of warmest month [°C]	24.5–28	29.4–32.5
	min. temperature of coldest month [°C]	-3.8–-0.63	1.9–5
	temperature annual range [°C]	27–29	25.6–28.8
	mean temperature of wettest quarter [°C]	18.5–22.8	19.4–22.5
	mean temperature of driest quarter [°C]	1.3–5	6.9–13.1
	mean temperature of warmest quarter [°C]	20–24	>24.4
	mean temperature of coldest quarter [°C]	1.3–4.7	5–10
Precipitation	annual precipitation [mm]	1187.5–1500	1625–2156
	precipitation of wettest month [mm]	194–200	265–413
	precipitation of driest month [mm]	16–34	43–95
	precipitation seasonality	56–65	47–60
	precipitation of wettest quarter [mm]	525–712.5	712.5–1000
	precipitation of driest quarter [mm]	50–106	169–337.5
	precipitation of warmest quarter [mm]	530–750	562.5–750
	precipitation of coldest quarter [mm]	62–112.5	184–337.5

re-interpolated the ASTER GDEM to the same resolution as the bioclimatic variables (2.5') using a spline function.

Topographic variables used in this research include altitude, slope and aspect. Slope and aspect were calculated using the Spatial Analyst Tools in ArcGIS (v9.3). Slope helps to identify the rate of maximum change in z-value from each cell and the range of slope values in degrees is 0 to 90 (ESRI 2008). Aspect identifies the downslope direction of the maximum rate of change in value from each cell to its neighbours and it can be thought of as the slope direction (ESRI 2008). The output raster value of aspect is the compass direction, in which aspect is expressed in positive degrees from 0 to 360, measured clockwise from north, east, south and again to the north. In this research, we defined the north-facing slope as 0° and the south-facing slope as 180°. As the aspect changes from north to south, it increases gradually from 0 to 180°. We used this technique to transform aspect values from a circular variable (0–360°) into a continuous variable (0–180°).

To reduce the deleterious effects of collinearity on model fit, the maximum coefficient allowed between pairs of variables was set to 0.7 (Dormann et al. 2013). Correlation coefficients amongst environmental variables are presented in Suppl. material 1: Table S1. We then selected the following ten environmental variables for use in fitting the model: altitude, slope, aspect, mean diurnal range, temperature seasonality, min. temperature of coldest month, mean temperature of wettest quarter, annual precipitation, precipitation seasonality and precipitation of warmest quarter.

Nature reserve and land cover data

We retrieved data on the spatial distribution of national nature reserves from the Nanjing Institute of Environmental Sciences, Ministry of Ecology and Environment of China (http://www.nies.org/). We also retrieved land cover data (2015) of 1-km spatial resolution from the Resources and Environment Data Center of the Chinese Academy of Sciences (http://www.resdc.cn/).

Model fitting

Many software algorithms can be used to calculate habitat suitability using only species presence data, such as Bioclim (Busby 1986), Domain (Carpenter et al. 1993), Garp (Stockwell 1999), NFA (Hirzel et al. 2002) and Maxent (Phillips et al. 2006). The Maxent is one of the machine learning algorithm models and it is one of the most widely used and well-predicted species distribution models (Phillips et al. 2006; Elith et al. 2006; Harte et al. 2008; Wisz et al. 2008; Phillips et al. 2009; Yackulic et al. 2013).

In this study, we used Maxent to evaluate habitat suitability in *M. o.* subsp. *officinalis* and *M. o.* subsp. *biloba*. We randomly selected 25% of the data entries for each subspecies for use as test data, with the remaining 75% being used to train the model (training data). The Maxent model parameters were set as follows: 'maximum iterations' was 500, 'maximum number of background points' was 10000, 'replicates' was 1 and 'replicated run type' was 'cross-validate'. The 'convergence threshold' was 0.00001 and the 'regularization multiplier' was 1.

The output ASCII grid produced by Maxent is continuous probability data ranging from 0 to 1, which represents the habitat suitability of a species in a specified region. Based on previous research (Liu et al. 2013; Li et al. 2014; Liu et al. 2016), we adopted 0.7 as the threshold to transform the probability data into binary data (0/1). Grids, with probability higher than 0.7, were defined as suitable habitats.

Percent contribution and permutation importance are approaches available in the Maxent software which evaluate the contribution of variables to model predictions. Percent contribution and permutation importance are estimated based on the model gain, which is closely related to the deviance and is used to measure the goodness of fit of the model (Phillips 2017). Percent contribution depends on the path that the model used to reach the optimal solution (Songer et al. 2012; Smarter et al. 2012), whereas permutation importance depends on the final iteration of the fitted model. It is expressed as the differences between the AUC (area under the receiver operating curve) values of presence and background points caused by variation in the predictor variables (Songer et al. 2012). It is worth noting that when pairs of variables are strongly correlated with one another, the percent contributions of each should be interpreted with great care (Phillips 2017). Therefore, in this study, we used permutation importance to assess the contribution of each environmental variable to the fit of the produced models.

We also fitted response curves to evaluate how habitat suitability responded to variation in the environmental variables. In order to reduce the effects of correlation

between pairs of environmental variables on model fit, each response curve was fitted using only one environmental variable. The fitted response curves are shown in Suppl. material 2: Figs S1–S6. Based on these response curves, we identified the characteristics of suitable habitats based on their environmental variables (Table 1).

Model validation

In numerous studies, only presence data (such as herbarium data) was available when attempting to model species distributions and habitat suitability. Absence data (negative records) are rare, despite their usefulness in assessing model specificity. Thus, it was difficult for us to use ROC (receiver operating characteristic curves) to evaluate the performance of the fitted models. Phillips et al. (2006) suggested an alternative approach which could avoid this issue through the distinguishing of presence from random, rather than presence from absence. In this way, ROC could be used to evaluate the performance of the fitted model.

In ROC, the ordinate axis represents the sensitivity, while the abscissa axis represents the false-positive fraction (1-specificity). The AUC (area under curve) is then used to measure the prediction success of the fitted model. AUC values range from 0 to 1; if AUC values are higher than 0.5, the imitative effect of the fitted model is deemed different from random (Fielding and Bell 1997). AUC values were then used to categorise model fits as follows (Swets 1988): poor (0.5–0.6), fair (0.6–0.7), good (0.7–0.8), very good (0.8–0.9) and excellent (0.9–1.0). In this study, the AUC calculated, based on the training data and test data, were both higher than 0.9 (Suppl. material 2: Fig. S7). This indicated that the fitted models performed excellently.

Assessment of conservation areas and the degree of human disturbance

We used overlay analysis and maps of national nature reserves and the identified suitable habitats to identify conservation areas where *M. o.* subsp. *officinalis* and *M. o.* subsp. *biloba* populations were likely to occur. We also used overlay analysis of land cover and the identified suitable habitats to calculate the percentage for each land cover type in the suitable habitats and evaluated the extent to which these habitats have been disturbed by human activity.

Results

Contribution of environmental variables

Amongst the ten selected variables, the environmental variables which most affected the distribution of *M. o.* subsp. *officinalis* were min. temperature of coldest month, followed by temperature seasonality and altitude (Table 1). Given that many of the environmental

variables were highly correlated with one another (Suppl. material 1: Table S1), we can reasonably conclude that extremely low temperatures (min. temperature of coldest month, mean temperature of driest quarter, mean temperature of coldest quarter) and temperature fluctuation (temperature seasonality and temperature annual range) are the most important variables which influence the distribution of *M. o.* subsp. *officinalis*. Both altitude and high temperature (max. temperature of warmest month, mean temperature of warmest quarter) also significantly influence the distribution of *M. o.* subsp. *officinalis* (Table 1), but to a lesser extent than extreme low temperatures and temperature fluctuations.

M. o. subsp. *biloba* seems to be more influenced by annual precipitation and extreme precipitation (precipitation of wettest month, precipitation of driest month, precipitation of wettest quarter, precipitation of driest quarter, precipitation of coldest quarter). Temperature fluctuation (temperature seasonality, temperature annual range, isothermality and mean diurnal range) also had notable influences on the distribution of *M. o.* subsp. *biloba*.

Habitat preference and potential distribution of *M. o.* subsp. *officinalis* and *M. o.* subsp. *biloba*

Habitats suitable for *M. officinalis* subsp. *biloba* are mainly located in central subtropical regions (Fig. 2). Small areas of suitable habitats could also be found in the northern areas of Taiwan. *Magnolia o.* subsp. *officinalis* habitats extend to locations in areas further north (Fig. 2), i.e. north subtropical areas. Habitats suitable for *M. o.* subsp. *officinalis* were also found in the south-eastern area of Tibet.

Compared to *M. officinalis* subsp. *biloba*, *M. officinalis* subsp. *officinalis* tends to grow at higher altitudes (Fig. 2) and is able to survive in areas experiencing greater fluctuations in ambient temperature, lower extreme temperatures, less precipitation and greater fluctuations in precipitation (Table 2).

Conservation areas and human disturbance

Overlay analysis of the identified suitable habitats and national nature reserves found that only 8.4% of the habitats suitable for *M. officinalis* subsp. *officinalis* were located in national nature reserves. Similarly, for *M. o.* subsp. *biloba*, only 3.4% of suitable habitats were located in national nature reserves. Thus, large areas of habitats, suitable for both subspecies, are not protected and are thus at risk (Fig. 2).

Overlay analysis of the identified suitable habitats and land cover found that the majority of land in habitats, suitable for both *M. o.* subsp. *officinalis* and *M. o.* subsp. *biloba*, is woodland and forest (based on area) (Figs 3, 4). Suitable habitat areas were also constituted largely by agricultural land, residential land and mining and industry land (Figs 3, 4). In addition, suitable habitats were found to contain significant areas of grassland.
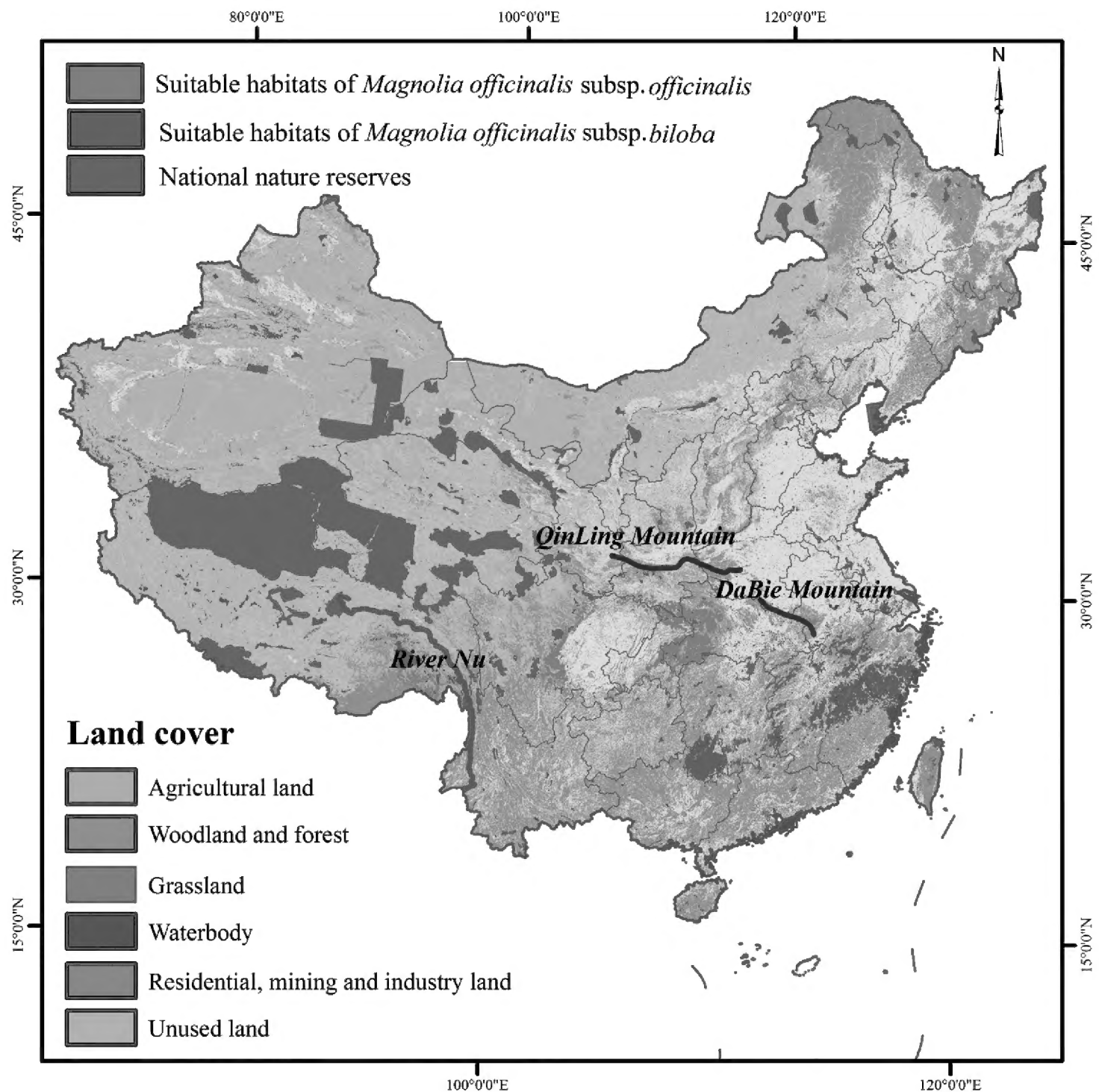
Figure 2. The spatial distributions of habitats suitable for *Magnolia officinalis* subsp. *officinalis* and *M. officinalis* subsp. *biloba*.

Discussion

Relationship between environments and the distribution of *M. o.* subsp. *officinalis* and *M. o.* subsp. *biloba*

The large-scale geographical distribution of vegetation is heavily influenced by the climate (Manthey and Box 2007; Punyasena et al. 2008). Amongst the myriad climatic variables, rainfall and temperature are the major factors which influence the distribution of vegetation; in particular, maximum and minimum rainfall and average temperature greatly limit the distribution and dispersal of vegetation (Thuiller et al. 2003; Crawford 2008). In our study, we found that extreme temperatures and precipitation
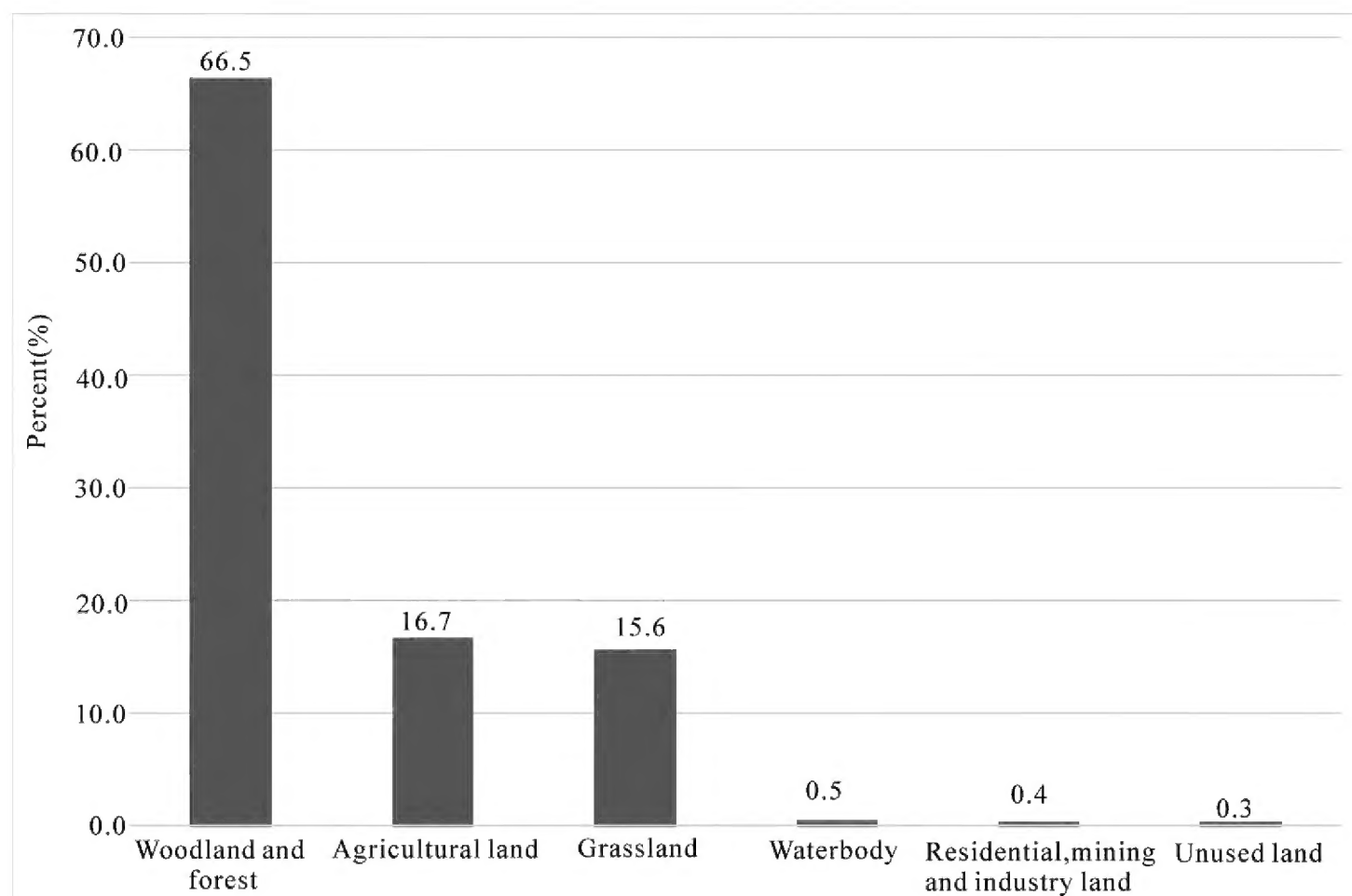
Figure 3. Land cover status (2015) within the suitable habitats of *Magnolia officinalis* subsp. *officinalis.*
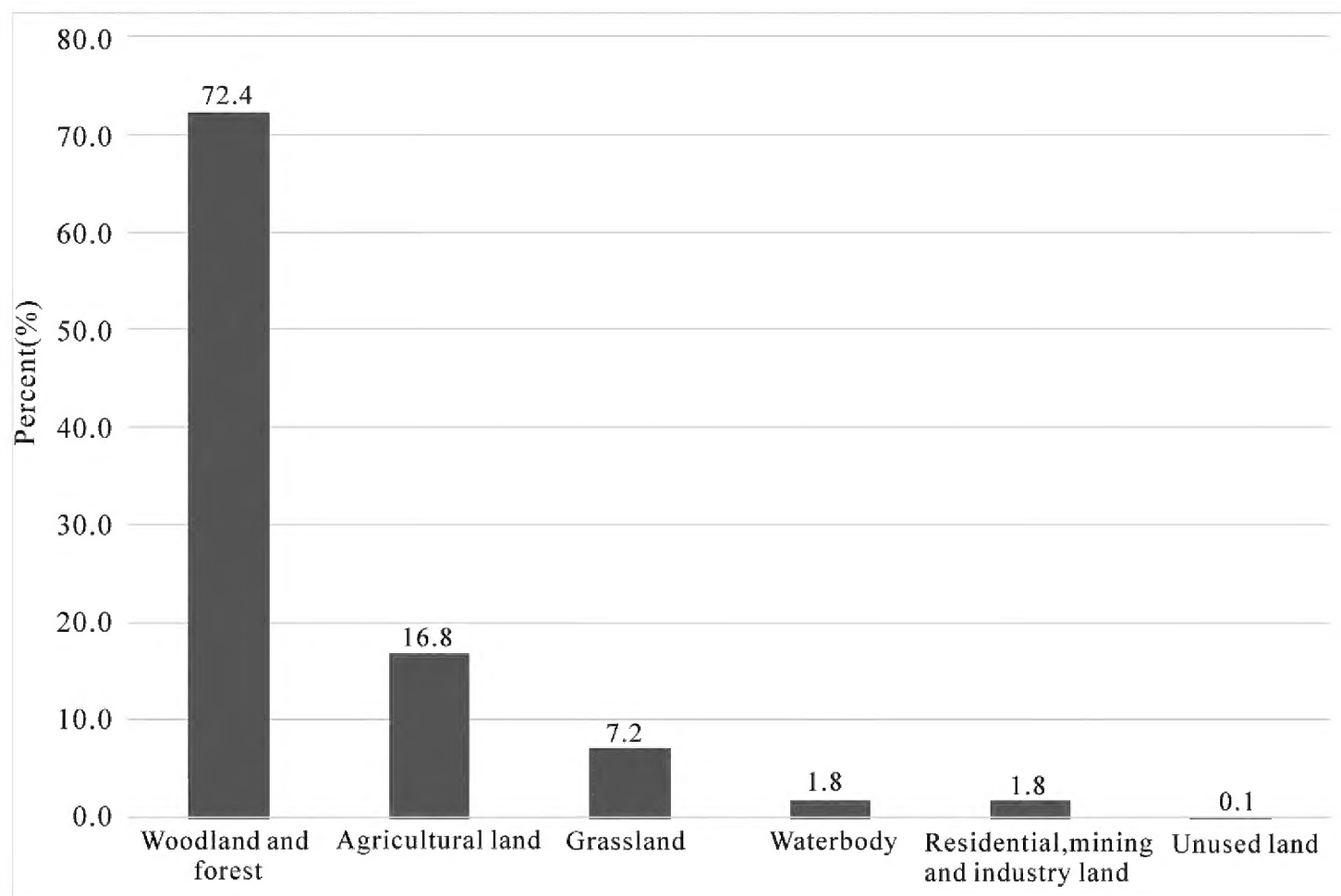

Figure 4. Land cover status (2015) within the suitable habitats of *Magnolia officinalis* subsp. *biloba.*

play important roles in determining the distributions of *M. o.* subsp. *officinalis* and *M. o.* subsp. *biloba* (Table 1). However, the most influential variables varied between the two subspecies. For *M. o.* subsp. *officinalis*, temperature (min. temperature of coldest month, mean temperature of driest quarter, mean temperature of coldest quarter) was the most significant determinant of distribution. Conversely, in *M. o.* subsp. *biloba*, precipitation (annual precipitation, precipitation of wettest month, precipitation of driest month, precipitation of wettest quarter, precipitation of driest quarter, precipitation of coldest quarter) had a greater influence on distribution than temperature.

The reasons for this difference may be due to the different habitat preferences of the two subspecies. Habitats suitable for *M. o.* subsp. *officinalis* are mostly located in northern and central subtropical regions at high altitudes (Fig. 2). These areas are vulnerable to the Siberian cold current, resulting in extremely low temperatures in winter (Table 2). Therefore, extremely low temperature is the most important factor which limits the survival and spread of *M. o.* subsp. *officinalis*. Conversely, *M. o.* subsp. *biloba* prefers warmer, more southern regions (central subtropical areas) at low altitudes (Table 2). In southern areas, where low temperatures become less limiting, precipitation becomes the most important factor which prevents *M. o.* subsp. *biloba* from spreading to more northerly regions (Fig. 2). We also found that temperature fluctuations greatly influence the distributions of both *M. o.* subsp. *officinalis* and *M. o.* subsp. *biloba* (Table 1). This finding was consistent with the hypothesis that temperature stability, in combination with sufficient rainfall, can promote colonisation by plant species (Slik et al. 2009; Zhang et al. 2013).

Threshold adopted to identify the suitable habitats

The output ASCII grid produced by Maxent is continuous probability data ranging from 0 to 1. A threshold is needed to transform the probability data into binary data (0/1) and to acquire the information about the spatial distribution of suitable habitats. In previous studies, 0.5 (Waltari and Guralnick 2009) and 0.8 (Ramírez-Barahona et al. 2009) were often used as arbitrary thresholds to transform the probability into binary data (0/1). Other thresholds, such as the minimum predicted value (Phillips et al. 2006), the 10th percentile training presence threshold (Brito et al. 2009), the 20th percentile training presence threshold (Donegan and Avendaño 2010), thresholds which result in a sensitivity of 95% (Newbold et al. 2009) and the maximisation of the sum of sensitivity and specificity (maxSSS) (Liu et al. 2013; Liu et al. 2016), have been utilised.

Maxent uses a variety of methods to determine thresholds, including the minimum training presence, 10th percentile training presence, equal training sensitivity and specificity, maximum training sensitivity plus specificity and so on (Suppl. material 1: Table S2). In this study, all thresholds estimated by Maxent were lower than 0.5 (Suppl. material 1: Table S2 and Table S3). Li et al. (2014) deemed that grids assigned prob-

abilities higher than 0.6 could be reasonably defined as suitable habitats. Additionally, Liu et al. (2013, 2016) investigated which thresholds could be used confidently to transform probability data into binary data (0/1), reporting that the thresholds calculated by most algorithms are lower than 0.8.

Wilson et al. (2005) contend that the appropriate threshold should be selected according to the purpose for developing the species distribution model. Our primary purpose in this research was to find the most suitable habitats for *M. o.* subsp. *officinalis* and *M. o.* subsp. *biloba* to aid in the conservation and plantation of both subspecies. Therefore, we used a larger threshold (0.7) to transform the continuous probability data into binary in order to ensure that only the most suitable habitats were selected, based on the assumption that areas exceeding the larger thresholds would be better able to support the conservation and plantation.

Conservation areas

Nature reserves provide effective refugia for wild plants. In this study, only a small number of habitats, suitable for either *M. officinalis* subsp. *officinalis* or *M. officinalis* subsp. *biloba*, were located in national nature reserves (Fig. 2). However, due to a lack of data, provincial, municipal and county-level nature reserves, forest parks, scenic spots and geological parks were unable to be included in our conservation area analysis. Therefore, the percentage of suitable habitats which are protected may in fact be higher than 8.4% (*M. o.* subsp. *biloba*) and 3.4% (*M. o.* subsp. *officinalis*).

Overlay analysis of land cover data and the locations of suitable habitats found that the majority of land in suitable habitats was woodland and forest (Figs 3, 4). However, plantations, including mulberry gardens, orchards and tea gardens were categorised within the "woodland and forest" category in the used datasets. It is thus difficult to know the exact proportion of plantation forests in the woodland and forest category. A considerable amount of land in suitable habitats was also used for agricultural land, residential land and mining and industry land (Figs 3, 4). Similarly, a large amount of land in suitable habitats was grassland (Figs 3, 4). In southern China, most grasslands are the result of secondary vegetation growth following deforestation. Therefore, we can conclude that human activities likely cause significant disturbances in habitats suitable for *M. o.* subsp. *officinalis* and *M. o.* subsp. *biloba*.

Limitations of this research

The geographical distributions of plants are heavily influenced by numerous environmental factors including climate, hydrology, soil, human activity and other factors (Gaston 2003). In our study, only climatic and terrain variables were used to assess habitat suitability. This limitation may have introduced some uncertainties into our assessments of habitat suitability. In addition, the latitudes and longitudes of some speci-

men collection sites were not directly recorded by GPS, being instead inferred from the names of the villages and towns near the collection sites which were recorded as background information for each specimen. Towns and villages are usually distributed in flat areas with low altitudes, which may have resulted in a tendency to assign lower altitudes than the actual altitudes of the sites from which the specimens were collected.

The habitat suitability assessment, conducted in this study, provides a scientific basis for the selection of priority protected areas in the conservation of *M. o.* subsp. *biloba* and *M. o.* subsp. *officinalis*. In addition to habitat suitability, the genetic diversity of endangered species needs to be considered when selecting priority areas for conservation (Cires et al. 2013). Genetic diversity plays a pivotal role in the maintenance of species populations (Beardmore 1983, Antonovics 1984, Yu et al. 2011). As we develop strategies for the conservation of threatened species, it is necessary to gain further insight into the genetic diversity in individual populations and that existing between populations (Hogbin and Peakall 1999; Yu et al. 2011). Previous studies have found that genetic diversity and population size are not always significantly correlated and the genetic diversity of populations of different sizes should be fully evaluated (Zhang et al. 2010). In conservation, proper attention should be paid to populations occupying smaller areas which have high genetic diversity, as they could be used to effectively reduce the loss of genetic resources (Zhang et al. 2010; Yu et al. 2011).

Prospects

Magnolia officinalis subsp. *officinalis* and *M. officinalis* subsp. *biloba* are closely related subspecies. However, there are marked differences in the geographical distributions of these two subspecies (Liu 1996). Few studies have investigated the characteristics and distributions of habitats suitable for these two subspecies. We mapped suitable habitats for both subspecies in China in this research (Fig. 2). Based on this information, we conclude that these identified suitable habitats should be selected as conservation priority areas in China to conserve *Magnolia* species or more natural reserves should be established to conserve these suitable habitats. This is very important for the *in situ* conservation of these subspecies. Moreover, the findings of our study can assist in the selection of suitable areas in which to cultivate these subspecies.

China is the ancestral home of the Magnoliaceae, with more than 40% of Magnoliaceae species having originated in southwest China (Wang and Jiang 2001; Cicuzza et al. 2007). In the past few decades, the survival of numerous Magnoliaceae species has been severely reduced by the activity of humans and many are greatly threatened by over-utilisation (for timber harvesting, bark, flower bud collection etc.) and habitat fragmentation (Wang and Jiang 2001; Cicuzza et al. 2007; Cires et al. 2013). According to the "China Biodiversity Red List," 71.7% of Magnoliaceae species are defined as "Threatened" (Ministry of Ecology and Environment of China and Chinese Academy of Sciences 2013). Therefore, it is necessary to properly evaluate habitat suitability and genetic diversity for species in this family and to provide scientific support for their conservation.

Conclusion

In this study, we found that the environmental variables, which influence species distributions, are different for each subspecies. The distribution of *M. officinalis* subsp. *officinalis* was primarily determined by variation in minimum temperatures, while the distribution of *M. officinalis* subsp. *biloba* was primarily determined by variation in precipitation.

We identified the habitats suitable for both subspecies and found that the two subspecies have distinct habitat preferences. Compared to *M. o.* subsp. *biloba*, *M. o.* subsp. *officinalis* is found in more northerly areas, grows at higher altitudes and is able to survive in areas experiencing greater fluctuations in ambient temperature, lower extreme temperatures, less precipitation and greater fluctuations in precipitation.

The results of this analysis could provide useful information to support the *in situ* conservation of both *M. o.* subsp. *officinalis* and *M. o.* subsp. *biloba* and could aid in the selection of cultivation sites.

In the future, field survey data on the distribution of *Magnolia* species should be included in the assessment of habitat suitability to offset the deficiencies with regard to the specimen data. Genetic diversity assessment should be performed, together with habitat suitability assessment to provide stronger scientific support for the conservation of *Magnolia* species.

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Supplementary material 1

Tables S1–S3
Authors: Chuangye Song, Huiming Liu, Jixi Gao
Data type: statistical data
Explanation note: **Table S1.** Correlation coefficients between pairs of environmental variables. **Table S2.** Thresholds estimated by Maxent for the fitted model of *Magnolia officinalis* subsp. *officinalis*. **Table S3.** Thresholds estimated by Maxent for the fitted model of *Magnolia officinalis* subsp. *biloba*.

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Supplementary material 2

Figures S1–S7

Authors: Chuangye Song, Huiming Liu, Jixi Gao

Data type: statistical data

Explanation note: **Figure S1.** Response curves of habitat suitability to variables of topography of *Magnolia officinalis* subsp. *officinalis*. **Figure S2.** Response curves of habitat suitability to variables of temperature for *Magnolia officinalis* subsp. *officinalis*. **Figure S3.** Response curves of habitat suitability to variables of precipitation for *Magnolia officinalis* subsp. *officinalis*. **Figure S4.** Response curves of habitat suitability to variables of topography for *Magnolia officinalis* subsp. *biloba*. **Figure S5.** Response curves of habitat suitability to variables of temperature for *Magnolia officinalis* subsp. *biloba*. **Figure S6.** Response curves of habitat suitability to variables of precipitation for *Magnolia officinalis* subsp. *biloba*. **Figure S7.** Receiver operating characteristic curves of the fitted models (Fractional predicted area: the fraction of the total study area predicted present; Omission rate: the proportion of the localities falling outside the prediction.).

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